

Investigation into the use of the Concept Laser QM system as an in- situ research and evaluation tool

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TOC

- Relevance of in-situ observation
- Concept Laser QM System overview
- QM Meltpool
 - Description
 - Marketed and NASA Uses
 - Current Results
- QM Coating
 - Description
 - Marketed and NASA Uses
 - Current Results
- Conclusion



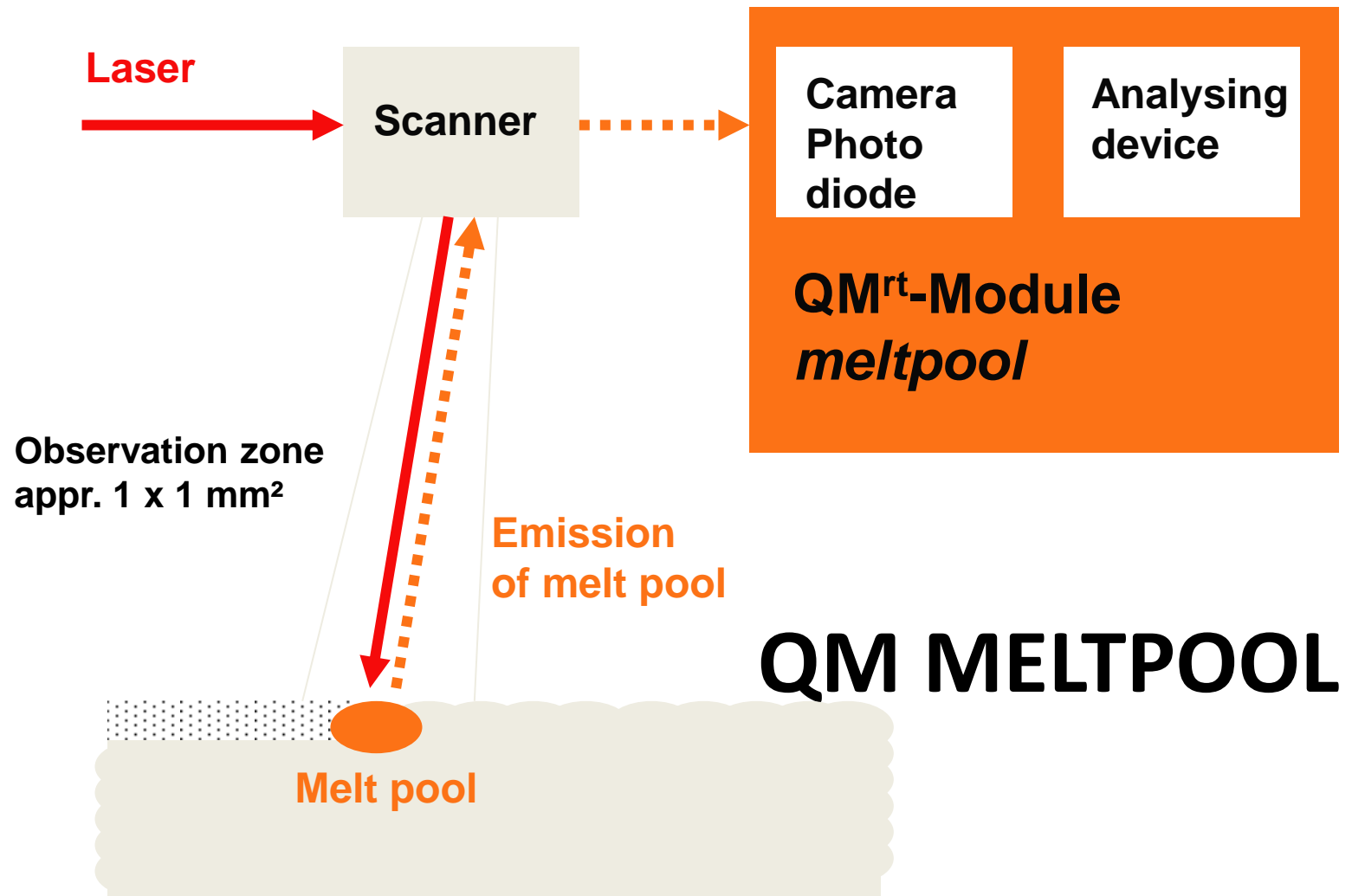
Relevance

- NASA Marshall Space Flight Center (MSFC) is investigating “printing” complex, expensive, and/or schedule intensive rocket engine components, using Direct Metal Laser Sintering (DMLS) which has shown clear advantages to other manufacturing methods
- As part of this effort, MSFC invested in Concept Laser technologies in order to refine our understanding of the printing process, and research the process sensitivities and resulting material properties
- Additionally, MSFC must develop a method to qualify printed components for space flight use, which indicates process control and inspection
- Both of these goals require in-situ process observation



CL QM System

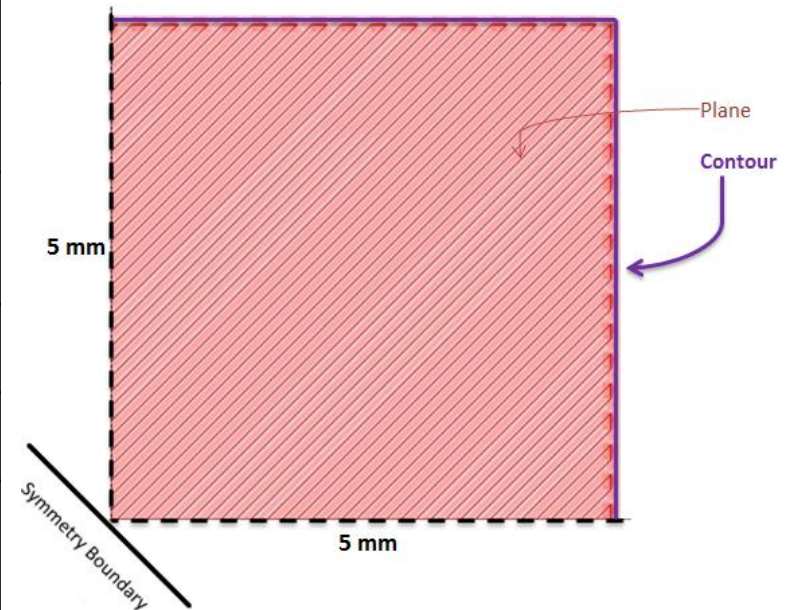
- MSFC invested in Concept Laser GmbH Quality Management (QM) modules on the M2 Cusing machine, which are marketed to provide process monitoring for a “quality-controlled fabrication process”
 - *“Quality management (QM) modules make it possible to ensure and document optimum component quality”* – concept-laser.de
 - Two in-situ modules are currently available and in-use: QM Meltpool and QM Coating
 - QM Meltpool monitors the molten area during a scan, using a near-infrared camera and photodiode. Data from this module is intended for post-process inspection to ensure conformance to a reference build
 - QM Coating monitors the powder layer surface and feedback control allows automatic adjustment of powder dose rates to minimize short feeds, while maximizing powder use
- So, can NASA use these to meet our process observation needs?



System Description

- A high-speed IR Camera measures the integrated intensity of the radiation and captures images. Software determines from camera images how many pixels are within a threshold color level corresponding to molten material
- A Photodiode measures the brightness intensity of the melt pool

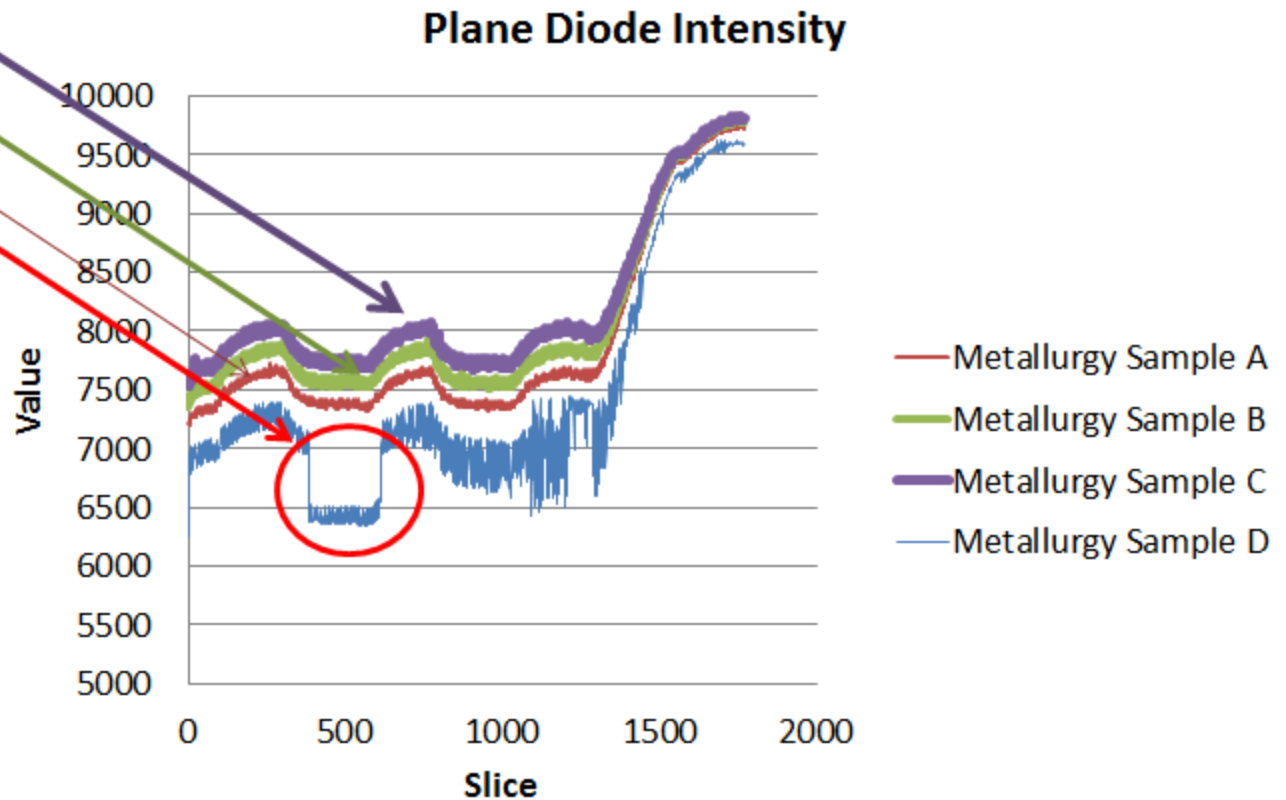
Part	Layer	Contour	Diode Intensity	From Photodiode, average intensity value of contour trace
			Meltpool Intensity	From Camera, average integrated IR intensity of contour trace
			Meltpool Area	From Camera, average number of pixels above threshold color level during contour trace
		Plane	Diode Intensity	From Photodiode, average intensity value of bulk material / hatch scan
			Meltpool Intensity	From Camera, average integrated IR intensity of bulk material / hatch scan
			Meltpool Area	From Camera, average number of pixels above threshold color level during hatch scan



Marketed Use

- Compare geometrically identical builds qualitatively to identify anomalies:

- Good
- Good
- Good
- Anomaly

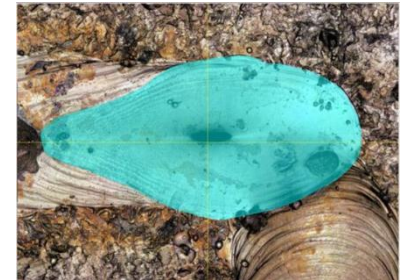
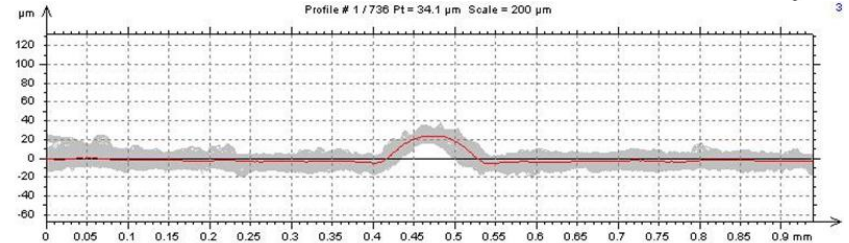
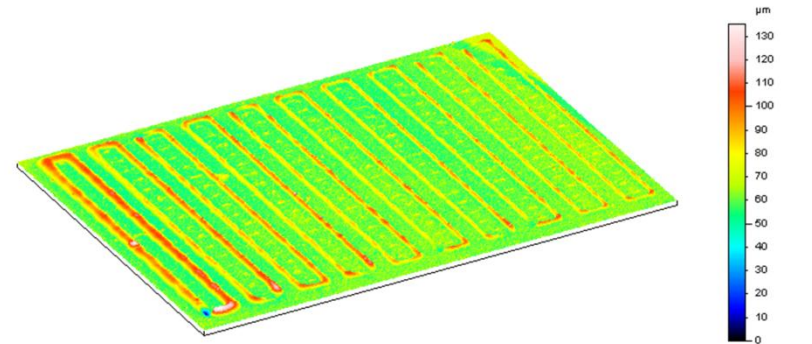


Potential NASA Use

- Research:
 - Identify how changing parameters change the size, shape, and temperature of the melt pool
 - Weld thermal gradients and melt pool / solidification path shape can strongly affect properties
 - Provide in-situ data to calibrate, and ultimately validate, computational process models (e.g. thermal history prediction)
 - Process improvement:
 - Can identify areas of heat buildup, and adjust parameters to reduce heat input to a goal value
 - Qualification:
 - Set quantitative boundaries on melt pool characteristics that are known to produce good material
- So, can we extract quantitative measurements from this qualitative system?

Quantification of Melt Geometry

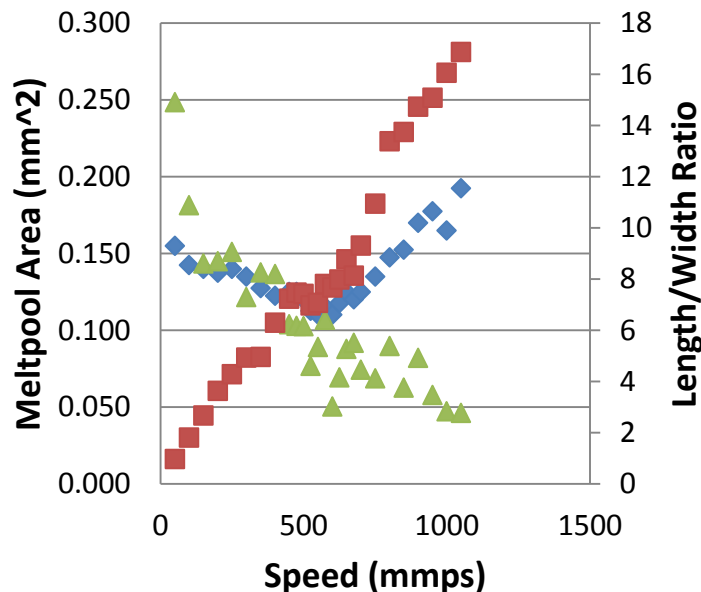
- Single track study:
 - Autogeneous welds made on In625 “baseplate”
 - Weld width and estimated bead area measured
 - Width measured using a Taylor Hobson Form Talysurf PGI 1230 stylus profilometer and verified by Wyko white light interferometer to an accuracy of $\pm 3\mu\text{m}$
 - Area *estimated* from a scanning laser confocal microscope image of the weld tail; capturing the final melt pool as the laser is turned off



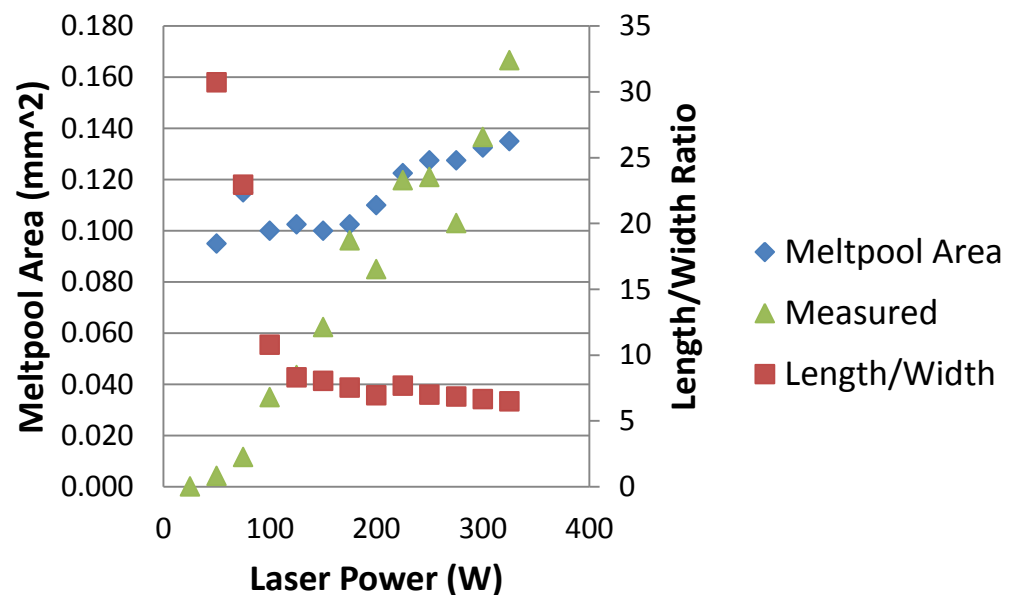
Melt Geometry Results

- Assuming a value of 0.0025 mm^2 per pixel, a melt area can be calculated
 - This area can be compared with the area estimates from microscope images
- Using this calculated area, and measured width, a L/W can be calculated

**Meltpool Size and Shape
(at Laser Power 180 W)**



**Meltpool Size and Shape
(at Laser Speed 600 mm/s)**

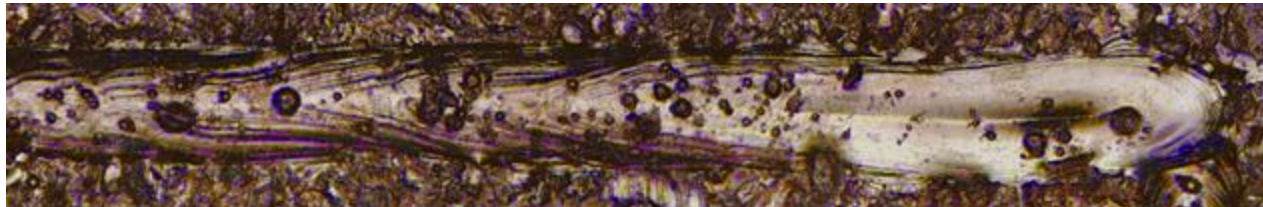


Application to Research

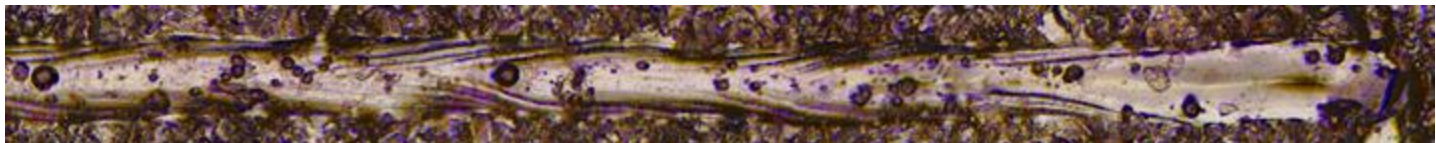
- Can observe trends in data to guide research
 - For example, clear transition region observed in graphs on previous chart; use this to guide hypotheses or observation of physical phenomena at this region
 - Before (100 mmps):



- During (400 mmps):

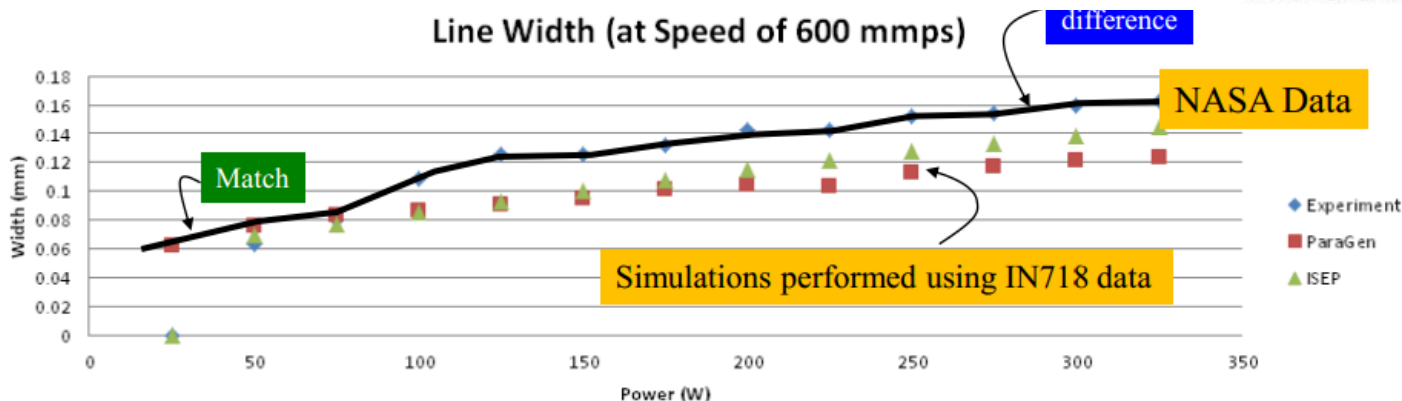
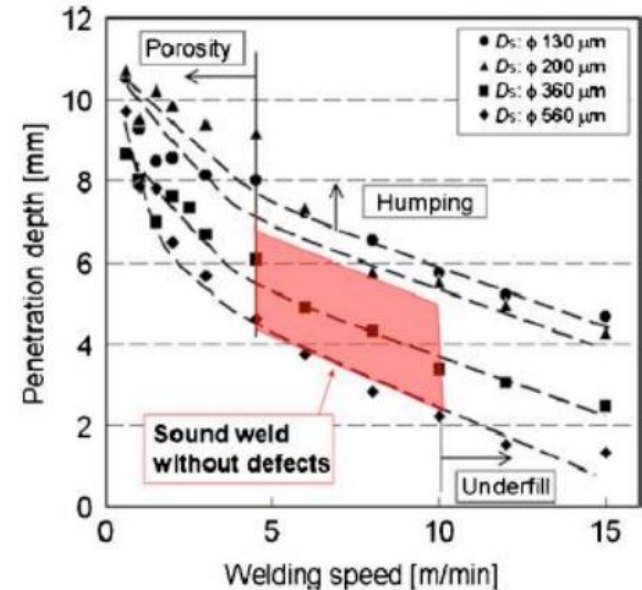


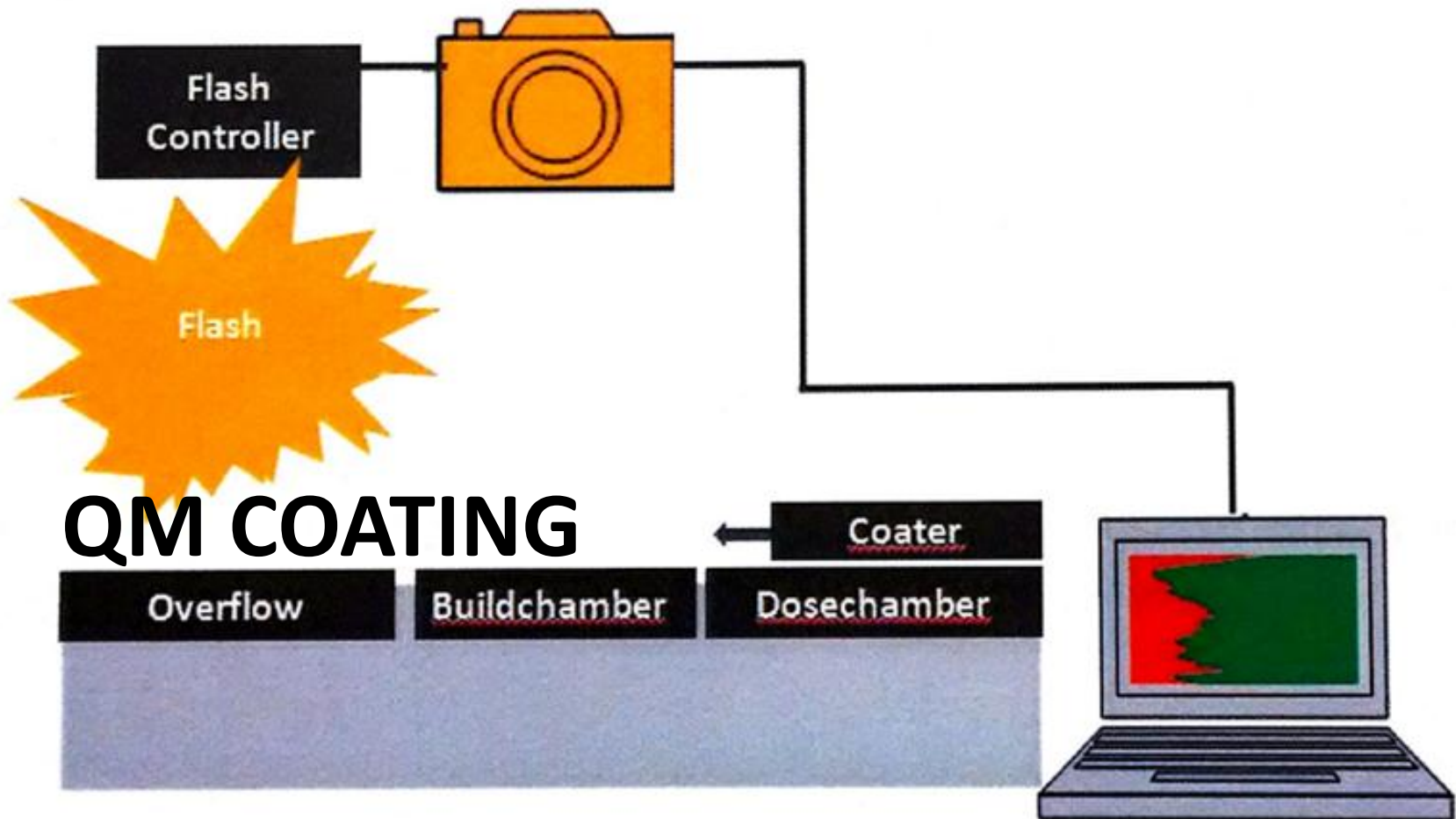
- After (1000 mmps):



Application to Process Modeling

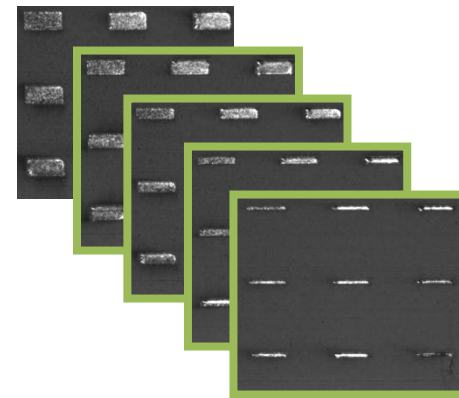
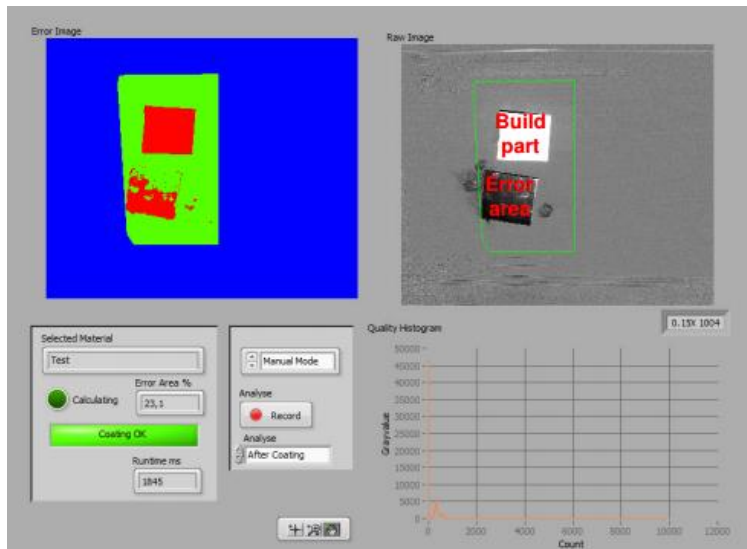
- Currently working with Applied Optimization (STTR), The Ohio State University (CIMJSEA), and internal code development (ER43) for powder-bed metals AM process modeling
 - Predict and offer solutions for defects





System Description

- A high resolution camera captures optical images before and after each powder layer is applied. QM Coating software compares grayscale values in a user-defined region of interest to determine sufficient (green) or insufficient (red) coated areas. If enough area is deemed to be insufficiently coated, the layer is re-coated to eliminate short feeds
- User can save images for a record of the build

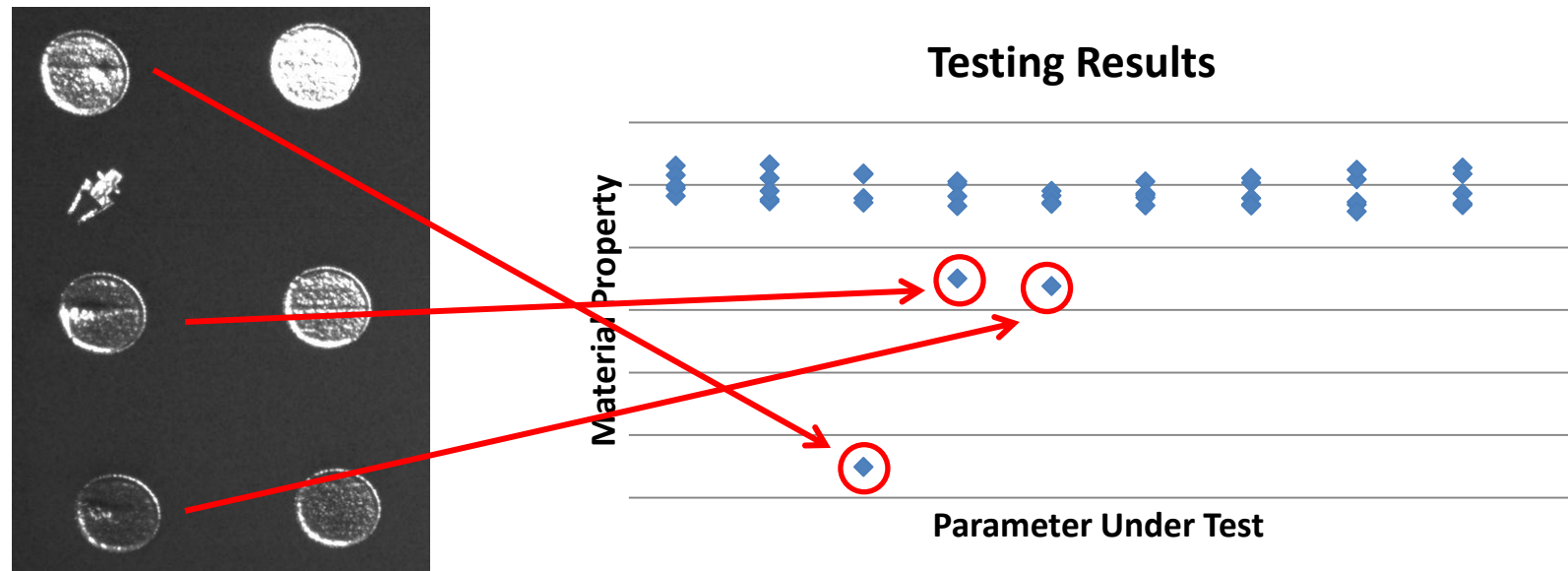


Use Description

- Marketed use is as a feedback-control system to operate autonomously during the build; e.g. recognize short feeds and correct the anomalies in-situ
- Potential NASA uses stem from the images providing a digital record of the build:
 - Documentation if required, or applied to a quality record
 - Non-destructive evaluation or failure analysis through layer-by-layer visual inspection
 - Internal or non-line-of sight geometry inspection (layer-by-layer)
 - Potential to develop software to reconstruct as-built geometry into a 3D model based on automatically determining the solidified material boundary in each layer

Application to NDE or Failure Analysis

- During build & test of ~50 tensile bars, engineers independently identified:
 - Anomalous tensile test results (→ failure analysis called for)
 - Defects observed in QM Coating images as tensile bars were printed (Visual inspection/NDE)



Conclusions

- QM Meltpool has been demonstrated to apply to NASA's uses in:
 - Research:
 - Can identify how input parameters change the size and shape of the melt pool
 - Can provide in-situ data to calibrate, and ultimately validate, process models
- Future investigations aim to justify QM Meltpool can apply to:
 - Process improvement
 - Qualification
- QM Coating has been demonstrated to apply to NASA's uses in:
 - Documentation, or applied to a quality record
 - Non-destructive evaluation
 - Failure analysis
- Future investigations aim to justify QM Coating can apply to:
 - As-built geometry reconstruction for internal or non-line-of-sight inspection

Questions?

